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A CARBON ARC SOLAR SIMULATOR

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INTRODUCTION

In 1959 it became apparent that there was a need to develop space environment facilities which could simulate true space conditions more accurately than was economically practical in the large diameter (over 10 foot) systems used in most aerospace research. The value of such a system could be to:

- (1) Resolve the differences in data obtained on larger, less sophisticated facilities
- (2) Evaluate the performance of cryogenic fuel tanks
- (3) Conduct experiments concerning materials and material properties, friction and bearings, leakage from seals, etc.

The design and operation of a pilot model of this type is described in the literature⁽¹⁾. Based on the experience and information gained from this small system, a larger facility has been designed and built. This paper describes the solar simulator to be used with the larger facility. This work is part of the research program in solar simulation being conducted at the NASA Lewis Research Center, Cleveland, Ohio.

DESIGN CONSIDERATIONS

Space Environment Simulator

This simulator has an inside test chamber which is six feet in diameter and nine feet high. It is shaped similar to a Dewar flask

⁽¹⁾Numbers in parantheses refer to similarly numbered references in bibliography at end of paper.

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with a three-foot diameter opening at the neck. The size of this opening through which the simulated solar radiation must pass was limited largely by the state-of-the art in casting fused quartz windows. Access to the chamber requires removal of this window. The space environmental simulator has the following characteristics and capabilities:

- (1) Capable of maintaining a pressure of 10^{-10} torr accomplished by first, mechanical and oil diffusion pumping to 10^{-6} torr and further reduction to 10^{-10} torr by cryogenic pumping by the test chamber walls at liquid helium temperature
- (2) Will have a sink temperature of 4.2 degrees Kelvin by virtue of the liquid helium cooled walls

Initially these conditions of pressure and temperature will be maintained for eight hours being limited by the helium supply.

Solar simulation was required to complete this facility. The space environment facility design requirements affect to a large degree the choice of solar simulation design. Since the environment within the chamber is a close approximation to the true space environment, the prime consideration in the solar simulator design was to approximate all the sun's characteristics as closely as possible compatible with the tank design. Other considerations such as cost, overall conversion efficiency (electrical watts in-vs. radiant watts out) and ease of operation were subordinated. The basic requirements were one solar constant over as large an area as possible (approaching a diameter of three feet) for eight hours of continuous operation.

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The Radiation Source

Because of the tank geometry (the narrow neck and a twelve-foot distance from the opening to the center of the test zone) a minimum collimation angle was required. This necessitated the use of a radiant source with the highest inherent radiance - the high intensity carbon arc.⁽²⁾⁽³⁾ Use of compact high-pressure xenon arcs as radiation sources would have required a multiple source design with a large increase in collimation angle. Gibon^s and Weinard⁽⁴⁾ have shown that the carbon arc will give radiation having a close approximation to the spectral distribution of a zero air mass sun. Based upon the above considerations the optical system was designed around a single high intensity carbon arc lamp.

The Optical Systems

Once the radiation source was selected, the choice of the optical collection system was based upon the requirements for uniformity and constancy of irradiance in the test zone and upon arc configuration. The condenser system uses refractive optics of fused quartz which collect radiation from the arc and directs it to the reflecting collimator.

Since the environmental simulator roughing pumps had adequate capacity, the collimator (fig. 1) was housed in a stainless-steel cylindrical enclosure evacuated to 10^{-3} torr by these pumps. The three-foot opening in this enclosure is joined to the test chamber at its three-foot neck. The fused quartz window separates the two vacuum

regions resulting in a differential pressure of 10^{-3} torr. This design provided the following advantages:

- (1) The source of radiation is located outside the enclosure.
- (2) The radiation enters the evacuated region of the optical enclosure through a small radiation entry port thereby reducing the size and cost of the main pressure-loaded window in this port.
- (3) Absence of water vapor and gases from most of the optical path thereby minimizing selective absorption.
- (4) Reduced pressure load at the space environment window thereby allowing use of a relatively thin, three-foot diameter window. This results in a reduction of window absorption, improvement of the spectral distribution and reduction of cost.
- (5) It gave assurance that the large optical elements will be protected and kept clean.

The choice of a reflector-type collimator, a quartz window in the collimated beam and eight-hour operating time allowed the use of an uncooled mirror. Since the quartz window is opaque to radiation beyond three microns, the heating of the mirror during use of the solar simulator does not contribute radiation to the test zone.

The last consideration was the choice between on-axis or off-axis collimation. An off-axis collimator was chosen to fulfill the requirements of uniformity and minimized black-reflectance. An off-axis system circumvented the problem of filling the hole in Cassegrain mirrors with radiation. Also, an off-axis system minimizes the possibility that radiation emitted or reflected by the test specimen will return to the test zone via the collimator.

SYSTEM COMPONENTS

Figure 2 is a sketch of the solar simulator optical system. The radiation from a 28 ^{kw} ~~KW~~ arc lamp is collected by condensing lenses which form an image of the arc at the radiation entry port. The flat mirror is required to direct the radiation from the horizontally burning arc into the vertical optical enclosure. A field lens in the radiation entry port serves a dual purpose. It is the main pressure loaded window and it, in conjunction with the collimator, forms an image of the condensing system in the test zone with maximum uniformity of irradiance. The image of the arc at the radiation entry port is at the focus of the collimating mirror. The mirror reflects the collimated radiation through the three feet diameter quartz window and into the test zone of the space environment simulator.

Radiation Source

The carbon arc lamp and condensing system developed for the solar simulator is shown in figure 3. It consists of a 16 mm. rare-earth cored, rotating positive carbon electrode operating at 400 amperes direct current. The lamp incorporates such features as water cooled jaws, automatic strike mechanism, positive electrode positioning, and the capability to allow joining of electrode extensions during lamp operation.

The automatic strike mechanism which is of the third electrode type not only is a convenience in lamp starting but also eliminates the irregular cratering of the positive electrode when the arc is struck. This minimizes the time interval to obtain constant radiance.

The positive electrode positioner is a small optical-relay system and sensor which maintains the protrusion of the positive electrode from its jaw a constant 16 mm. plus or minus $1\frac{1}{2}$ mm. It is necessary to maintain the electrode position to this tolerance not only to prevent arcing to the positive jaw, but also because the positive electrode is at the focus of the optical system.

One disadvantage of carbon arcs lies in the finite length of the consumable electrodes. To overcome this disadvantage and therefore extend the operating time for this lamp, the electrodes are joined by threading together. As the end of the operating carbon enters the arc lamp housing, another carbon is manually threaded into it and becomes an extension of the operating carbon. As the junction of the electrodes enters the arc gap there is a 15 second period of arc instability usually accompanied by a 7 percent decrease in radiance. Rapid consumption of the final thin section of the operating electrode is compensated for by accelerated positive feed by the positive electrode positioning device. The standard positive electrode is about 22 inches long and is consumed at approximately $3/4$ inch per minute. Therefore joining of positive electrodes is required every 30 minutes. Negative electrode feed rates are much slower - about $1/16$ th of an inch per minute. The standard $7/16$ inch diameter negative electrode is 12 inches long but can be obtained in lengths up to 24 inches. With a 12 inch standard negative electrode, joining is only required after two hours of continuous operation.

Condensing System

The purpose of the condensing system (fig. 2) is to collect the radiation from the arc and present it to the collimator to meet the irradiance requirements. Because of the radiance limitation of the source, the losses due to the optical system, and the long focal length of the collimator, the arc must be magnified four times. The condensers accept radiation from the arc at $f/1.5$ and deliver it to the radiation entry port and to the collimator at $f/6.0$. An image of the condensing lenses is focused at the test zone by the field lens (in the radiation entry port) and collimator with a magnification of 4.3 times which is a diameter of $26\frac{1}{2}$ inches. Within this area the target is uniformly irradiated with one solar constant with the simplest of condensing lenses, as shown. This $f/1.5$ condensing system is the present limitation on test zone diameter. The arc lamp can accept up to an $f/1.0$ condensing system which will uniformly irradiate a 32 inch test zone. The diameter of the fused quartz window then becomes the size limitation for the test zone.

The condensing system consists of three simple plano-convex lenses (six inches in diameter) made of fused quartz and finished to condenser accuracy. The first two (each of 20 inch focal length) are fixed. These two lenses form a virtual, magnified (approximately four times) image of the source behind the positive electrode. The third condenser (19 inch focal length) provides a fixed focal plane with variable magnification based on the zoom lens principle. It is on a movable mount. The center position of its range of movement is located

so as to place the lens at a two times focal length (38 inches) distance from the virtual image of the source. It forms a real unity-magnified image of the virtual source at the focus of the collimating mirror. This movable lens along with a radiation detector and servo-mechanism acts as a constant irradiance controller.

The total radiation detector placed either in the test zone of the simulator or at a mirror image of the test zone (located externally) is initially calibrated to one solar constant. During lamp operation any departure from this irradiance set point caused by any reason will result in movement of the third lens along the optical path by the controller. Motion of the lens toward or away from the arc increases or decreases the amount of radiation accepted by the system and maintains the irradiance constant. The limits of lens travel is $2\frac{1}{2}$ inches. (This gives a range of irradiance control of .75 to 1.25 solar constants at constant average arc radiance.)

Because of their proximity to the arc the lenses are held in water-cooled copper lens holders.

Dirt on the condensing lenses has never been a serious problem. The lens nearest the arc is subjected to occasional pitting by fragments hurled from the positive electrode. This lens is replaced after 50 hours of operation.

Collimating Mirror

The collimating mirror is spherical and is of astronomical type and quality. It has a diameter of $3\frac{1}{2}$ feet and a focal length of 15 feet. Calculations show that there would be no optical advantage in

using a parabolic mirror in this system. The radiant heat absorbed by the mirror is acceptable for the present capabilities of the space simulator. Reradiation by the mirror to the test zone is obviated by the quartz window, as already discussed.

Fused Quartz Window

The three foot diameter fused quartz window which separates the optical enclosure from the space simulator is one inch thick. However, because of the low pressure differential, any reasonable thickness would have been sufficient. The one inch thickness was based on the manufacturer's suggestion for safety, ease of fabrication, handling and adaptibility to use as a seal. The window is polished to a commercial plate glass finish.

SYSTEM PERFORMANCE

The carbon arc has been operated for approximately 50 hours and has burned continuously for periods of up to four hours. In operation, the arc consumes 28 kw of power. The intensity of total radiation of the arc is constant to ± 3 percent when measured with a thermocouple of approximately one second time constant. The variation is cyclical and is associated with the rotational speed of the positive carbon and the sensitivity of the positive electrode positioner.

Long term drift (10 to 15 minute period) occasionally occurs. At present such drift is corrected by the operator who manually adjusts the gap or the lamp power supply. Normally, the lens in the constant irradiance controller operates over a range of plus or minus one inch from its set point. A limit switch located at the limits of lens

travel signals the operator if long term drift of the lamp's radiant output requires manual adjustment to the lamp or power supply.

Preliminary measurements on this solar simulation system are as follows:

1. Irradiance is one solar constant (1400 watts per square meter) ± 2 percent when monitored for long term drifts.

2. The system passes the spectrum between wavelengths of 0.25 and 3.0 microns. Using Johnson's zero air mass solar distribution⁽⁵⁾ as a standard, tolerances on spectral distributions are:

(a) Wavelengths from 0.25 to 0.40 microns ^{is} ± 10 percent

(b) Wavelengths between 0.40 and 1.20 microns in 0.10 micron bandwidths ^{is} ± 10 percent

(c) Wavelength between 1.20 and 3.00 microns in 0.30 micron bandwidths ^{is} ± 10 percent

3. The half angle of collimation is about one degree.

4. Uniformity of irradiance over a volume bounded by a $26\frac{1}{2}$ inch diameter area at the center line of the test zone and extending ± 18 inches along the optical center line is ± 2 percent.

5. Back reflection is negligible.

From the preliminary results it can be seen that the system has the capability of one solar constant over an area approaching three feet in diameter for eight hours of continuous operation.

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Figure 1. - Space environment simulator.

Figure 2. - Solar simulator optical system.

Figure 3. - Arc lamp and condensing system.

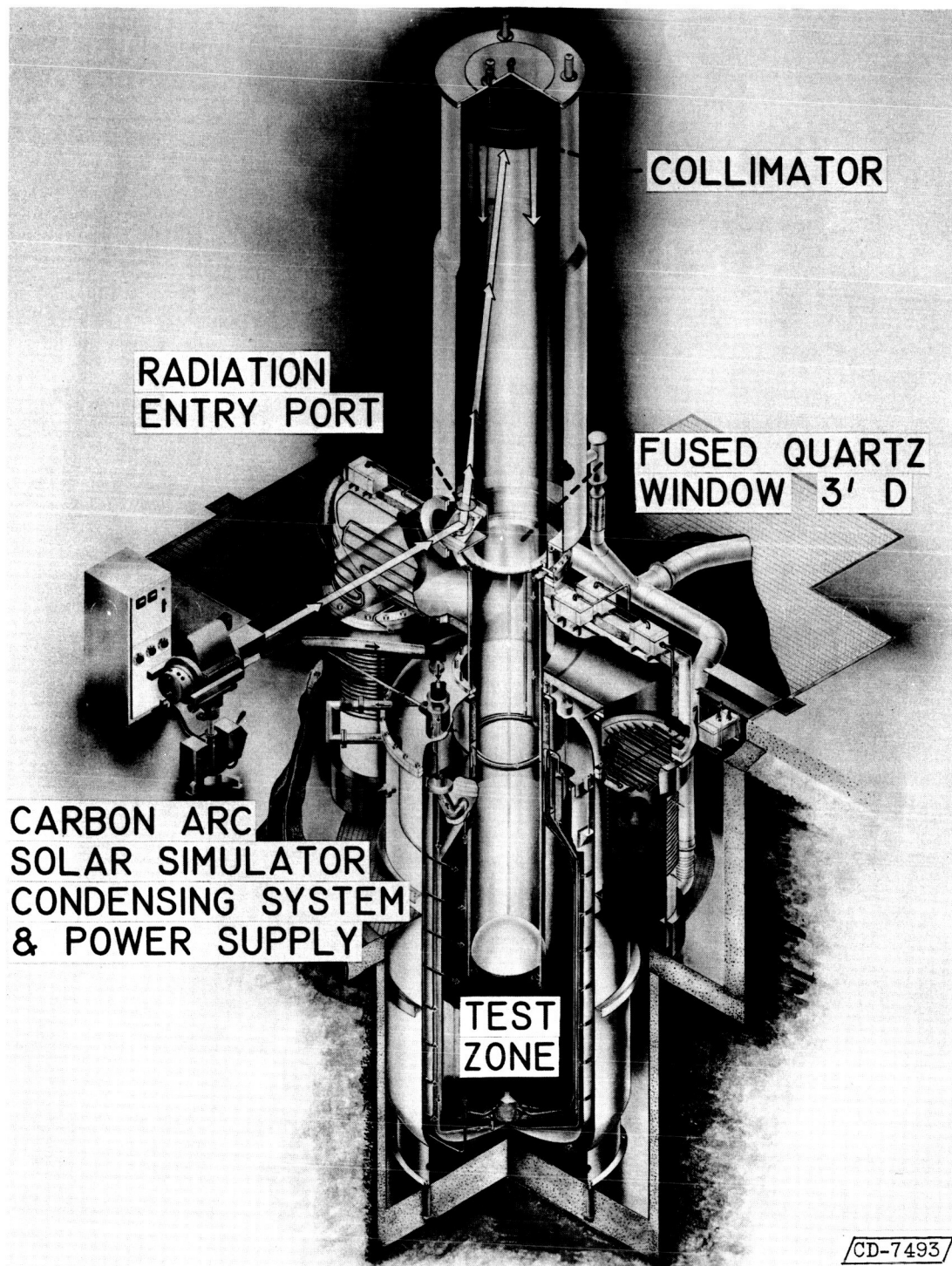


Figure 1. - Space environment simulator.

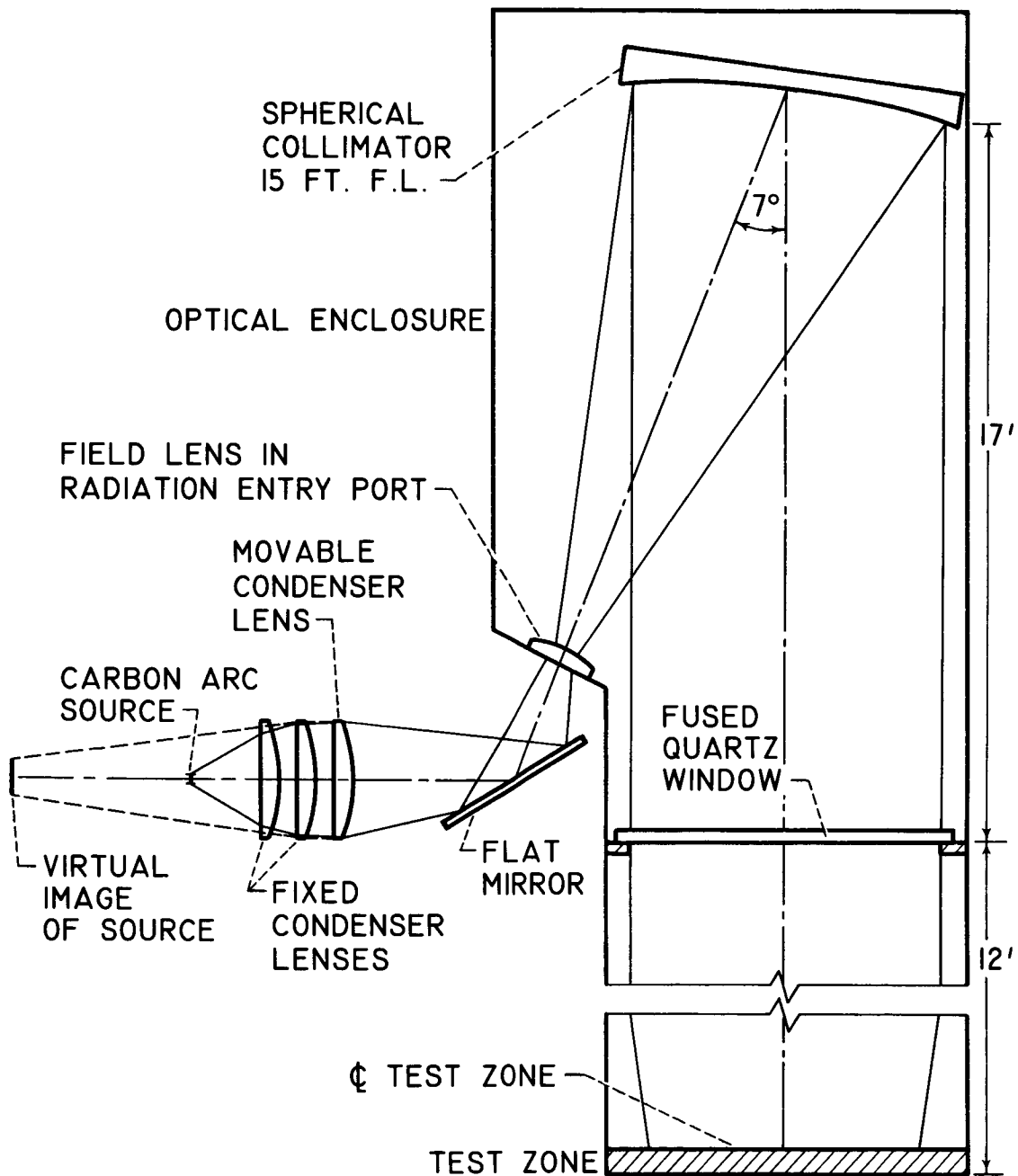


Figure 2. - Solar simulator optical system.

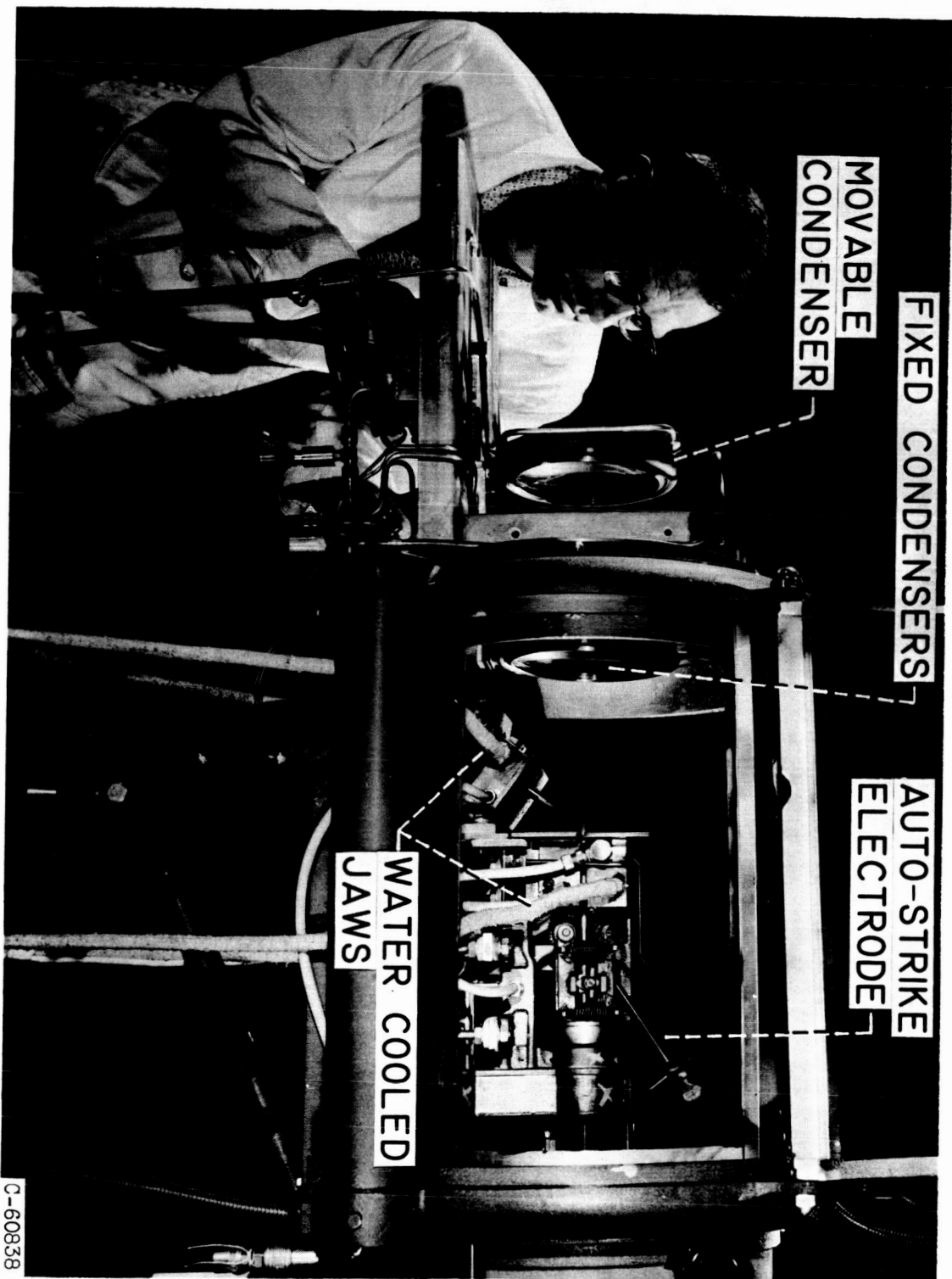


Figure 3. - Arc lamp and condensing system.